Minnesota
NASW-
RC#1

Calif NSG-318
RC#2

38 p.

N65 16491	
(ACCESSION NUMBER)	(THRU)
38	1
(PAGES)	(CODE)
CR 53791	29
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FACILITY FORM 602

[redacted]

(NASA CR-53791)
CAT-28

UNPUBLISHED PRELIMINARY DATA

Double order

The Positron-Electron Ratio of Precipitating Electrons

Laurence E. Peterson* (Calif. U.) [1963] 38 p refs
0558361

University of Minnesota, Minneapolis, Minnesota

1653302

(NASA Grant NsG-318 - in NASA Contract
NASW-56)

GPO PRICE $ ________

OTS PRICE(S) $ ________

Hard copy (HC) 2.00

Microfiche (MF) .50

* Presently at the University of California at San Diego, La Jolla, California where this work was completed.

[redacted]

RC#2
NsG-318

Abstract

A balloon observation of the x-ray spectrum from 37 to ~~400~~ 700 Kev over Minneapolis during the July 1961 solar event series has allowed an upper limit to be placed on the ratio of positrons to electrons during a precipitation, as well as on other geophysical processes. The electrons caused the x-ray bursts; no large fluxes above cosmic-ray produced background were observed above about ~~200~~ 400 Kev. The excess flux at 0.5 Mev, which would be caused by positrons annihilating was 0.051 ± 0.043 photons/cm^2-sec over a 68 minute interval at 2100 UT (1500 local) on July 13. No solar protons of energies greater than air cutoff (80 Mev) were observed during the flight. A limit of 33 ± 26 protons/cm^2-sec in the 1-15 Mev range can be obtained from the 0.5 Mev flux, which would be procuded via nuclear reactions. During the same interval, INJUN I observed a flux of 2×10^3 protons/cm^2-sec of 1-15 Mev solar protons at 1000 km only a few geomagnetic degrees further north. The differential electron spectrum producing the x-rays was fitted to a power law in energy with an exponent of 5.4. The average rate of electron precipitation was 6.4×10^7 electrons/cm^2-sec > 37 Kev, or 2.6×10^{10}/cm^2 over the 68 minute interval. This would deplete the outer zone of electrons in a few minutes, implying a steady and efficient acceleration mechanism. The limit on the ratio of precipitating positrons to electrons is $(4 \pm 3) \times 10^{10}$, which is also probably typical for electrons in the earth's magnetosphere, and may even apply to the interplanetary medium and the solar corona. The ratio should be compared with the upper limit of 2.5×10^{-9} for thermal electrons in our galaxy, obtained from the limit of the flux at 0.5 Mev in space.

Author

[redacted]

Introduction

This paper describes the result of an experiment in which the γ-ray spectrum to about 700 kev was observed at balloon altitudes over Minneapolis during an x-ray event. The event, associated with the July 1961 series of solar-terrestrial disturbances, has been interpreted as an electron precipitation. The resulting x-ray spectrum at low energies allows one to determine the spectrum and number of stopping electrons. A limit on the number of stopping positrons was determined by observing the γ-ray line at 0.5 Mev. The positron-electron ratio can thus be determined in this manner. The observation allows a much lower limit to be placed in this ratio than was previously available.

Apparently, little attention has been previously given to the possible existence of naturally occurring positrons in the earth's magnetosphere, although considerable effort has been devoted to studying the number and spectra of electrons trapped in and precipitating from these regions. Indeed, in many analyses, it has been tacitly assumed that the positron flux can be neglected. The x-ray flux, for example, generated by bremsstralhlung from 100 kev electrons stopping in the atmosphere or in an aluminum satellite body is produced with an efficiency on the order of 10^{-3} to 10^{-4}. A stopping positron, however, produced annihilation γ-rays with an efficiency of two. The fact that one can obtain reasonable auroral electron fluxes by observing x-rays from balloons [Winckler, et.al., 1962], and can obtain information on the outer zone electrons via their radiation [Arnoldy, et.al., 1962], implies an upper limit on the positron-electron ratio of about 10^{-4}. Direct measurement of the positrons in the trapped radiation has only recently been attempted [T. L. Cline, private communication].

The Experiment

The schematic of the measurement is indicated in Figure 1. Electrons, having energies up to a few hundred kev, will stop mainly by collisions in the first few tenth gm/cm^2 of atmosphere. A weak x-ray flux will be generated and will penetrate to balloon depth. A positron will behave similarly until it stops, then it will annihilate. The resulting γ-rays also are counted on the balloon detector, and their spectral and time variations observed. Since the fundamental electromagnetic processes are well understood the electron and positron flux can be calculated.

The balloon apparatus, which has been described previously [Peterson and Nitardy, 1962] consists of a phoswich type scintillator counter. The inner NaI(Tl) crystal is 3/4" long and 1" diameter. The outer plastic shield crystal has about a 0.5 cm wall. The differential pulse-height spectrum is obtained with a 37 kev window whose bias is scanned in 16 nearly linear steps from 37 kev to 670 kev. About four minutes are required for a complete scan. Scaled down counting rates from the window are telemetered. In addition, a Geiger counter [Masley, et.al., 1962] is used to monitor the charged particle rate, and compare them with other flights in the series.

The balloon flight (Minnesota M-255 of the July 1961 series) was launched at 1900 UT on 13 July and provided data from about 6 gm/cm^2 until after 0500 UT on 14 July. The rate and altitude history of the flight is shown in Fig. 2. The x-ray influx was in progress as the balloon reached ceiling at 2100 and decayed thereafter. Higher energy channels of the scintillator were not significantly above cosmic-ray produced background at any time during the flight, while the rates at low energies varied in order of magnitude. The excess photon spectrum is therefore very steep compared to the background. The G-M counter rates agreed very well with those expected from galactic cosmic rays and with other flights in the series. Its variations are due to the small depth changes of the balloon.

Solar-Terrestial Relations

The July 1961 series has been described in some detail by other workers [Hofmann and Winckler, 1963; Pieper, et. al., 1962] who have correlated balloon and satellite observations of electrons and protons with solar, radio, and geomagnetic effects. Class III flares at 1620 UT 11 July and 1000 UT July 12 initiated the events which occurred during this balloon flight. Both these flares produced solar cosmic-rays. The first flare most likely caused the sudden commencement (S.C.) magnetic storm and simultaneous Forbush decrease which started at 1112 UT on July 13. The second flare probably caused the magnetic storm of 0812 July 14. Later flares produced terrestial disturbances which extended nearly to the end of July.

Solar cosmic rays from the July 11 flare were first detected over Kiruna, Sweden at about 1930 July 11 [Hofmann and Winckler, 1962] and over Fort Churchill, Canada, at 2037. The flux of protons greater than 80-Mev went through a maximum before 0000 UT July 13, and was decreasing at the time of the sudden commencement. During this period no effects were observed over Minneapolis since the normal geomagnetic cut-off of 400-Mev was operating and the solar proton spectrum apparently did not extend to this energy. Protons in the 1-15 Mev range were observed starting from 1713 UT July 12, and were also detected by their absorption of cosmic noise over College, Alaska. The absorption reached a maximum at the time of sudden commencement. These low energy protons also produced a weak flux of nuclear γ-rays which was detected over Fort Churchill by the Minnesota group [Hofmann and Winckler, 1962].

The sudden commencement occurred at 1112 UT 13 July, the equatorial field was observed to reverse about 1550, hence flight M-255 occurred well into the main phase of the storm, and during a period of considerable magnetic activity. The horizontal field component at Fredricksburg is reproduced in Fig. 2. During this period the INJUN satellite observed large fluxes of 1-15 Mev protons at 1000 km at equivalent latitudes nearly as far south as Minneapolis. These fluxes reached a maximum early in the main phase of the storm and were slowly decreasing at the time of the flight [Pieper, _et_. _al_., 1962]. At no time during the flight M-254, which preceded M-255, and flight M-256, which overlapped and followed it, was any excess radiation observed with ion chambers and G.M. counters over Minneapolis.

Indeed these flights followed the Forbush decrease. The series of observations by the Minnesota group at Minneapolis and Fort Churchill is shown in Figure 3. The relatively weak x-ray flux seen by the scintillator on flight M-255 could not have been detected with the cosmic-ray instrumentation.

Balloon flights at Fort Churchill also indicated the decrease of the solar protons after the sudden commencement as measured by their secondary nuclear γ-rays, and in addition recorded large and sporadic x-ray influxes at the time of the sudden commencement and in the very disturbed times following it. Unfortunately, there is no simultaneous flight at Fort Churchill coincident with the initial burst on M-255. The many fluctuations observed on a Churchill flight after 2300 UT do not correlate in detail with the variations observed during the Minneapolis flight. The evidence is that electron precipitations may be of a rather local nature [Winckler, et. al., 1962].

The possibility of x-rays direct from the sun, rather than being locally produced, do not seem likely even though the first influx occurred at 1500 local time. There were no outstanding coincident visible, or radio solar events [A. Maxwell, private communication; G. Moreton, private communication], further solar x-ray events have thus far been observed with a time scale of minutes rather than hours. Simultaneous observations at two latitudes can indicate a solar origin, however, there was no Churchill flight during the first influx, and the one during the second burst was swamped by a much higher and more erratic flux or auroral x-rays. Solar protons having energy less than the air cutoff (80 Mev) above the balloon, but higher than the geomagnetic cutoff existing at the time can produce nuclear γ-rays. The steep photon spectrum however, is clearly inconsistent with these γ-rays, which would have energies up to about 8 Mev. The riometer at Minneapolis was inoperative at the time of the first influx, however no detectable absorption was noted earlier in the day, or later on during the flight.

We then continue under the idea that the steep excess photon flux must be due in major part to radiation from precipitating electrons having energies up to several hundred kev. The electrons most likely have their origin in the magnetosphere and may be either accelerated locally or dumped from the trapped radiation zones by the disturbed field [Winckler, et. al., 1962]. No outstanding magnetic event correlates precisely with the dumping. Periodicities in the rates, and other fine structures, sometimes observed, apparently were not present during this event. The general precipitation appears to be an intense version of certain x-ray events observed in the auroral zone [Anderson, 1960]even when the world-wide magnetic field was relatively undisturbed.

The Photon Spectrum

In order to facilitate analyses, the flight at altitude has been broken into a number of periods as indicated in Table I, and the rates have been averaged over these intervals. The last two hours of the flight are taken to be quiet time, and representative of the cosmic-ray produced background. Typical counting rate spectra are shown in Figure 4 for the quiet time period, and for the first influx.

Quiet time rates are compared with those obtained on a previous flight with the same detector in Figure 4. The statistical significance of the data in the higher energy channels has been improved by using rates for the entire flight. This procedure is valid since no gross variations were observed above about 380 kev, and results in sufficient resolution to indicate the presence of the 0.5 Mev γ-ray line produced by cosmic rays [Peterson, 1962]. The very near agreement of the spectra in Figure 4 shows the quiet time fluxes to be truly cosmic-ray produced background, and confirms the validity of subtracting these rates from those obtained during influxes to obtain the excess.

At higher energies, it was not always possible to do a channel-by-channel reduction because the scanning rate and counting rate were of the same order, resulting in an occasional ambiguity in the channel number for a given group of counts. The instrument was designed for high counting rates. Therefore, in order to obtain a better measure of the rates during a given period, all the counts in channels 10-16 have been combined together for the various periods. These channels cover roughly 400 to 670 kev, and include the line at 0.5 Mev. Even then, the excess rates obtained over all these channels during the most outstanding influx is so small as to be barely statistically significant. Obviously, there were very few photons near 0.5 Mev.

The excess counting rate is shown in Figure 5, for the first influx. The errors are the resultant standard deviation due to counting statistics. The shape of the excess spectrum averaged over different bursts was similar; the absolute values differed, and the significance of the excess was less at higher energies because of the lower differential counting rates. The excess photon spectrum derived from the first influx will be used in further analysis.

Under the assumption that all the excess x-rays are produced externally or near zero depth, the differential spectrum at the top of the atmosphere may be found quite simply. The counting rate in a detector of omnidirectional geometry factor G_o at a depth h due to a differential photon spectrum N(E)dE produced isotropically at the top of the atmosphere is:

$$R(E,h) = \frac{G_o}{2}\eta(E)C(h,E)N(E)\Delta E = F(E,h)N(E).$$

One-half of the photons are assumed lost upward, ΔE is the channel width, C(h,E) is a factor which takes into account the absorption in the atmosphere and in the G-M counter, which was located immediately above the scintillator. The factor C(h,E), which involves the Gold integral, is derived in the appendix and listed for the median energy of each channel in Table II. Efficiencies, $\eta(E)$, are taken from the work of Reynolds, et.al. [1957].

In Table II are also listed the uncorrected excess rates, the other parameters involved in the correction and the resultant photon spectrum at zero depth. The errors are due to the counting statistics. Systematic errors, due to uncertainties in the calibration, effective geometry factor, and neglect of multiple Compton scattering are probably small and have been neglected. The very steep differential photon spectrum at the top of the atmosphere is shown plotted in Figure 6.

Most likely, all the excess counting rates in channels 10-16 , if indeed there were any, are due to the high energy tail of the photon spectrum.. If however we assume that all these counts were due to photons at 0.5 Mev, we may place a limit on the excess flux due to this line. At 0.5 Mev, $F(E) = 0.322$, and the upper limit becomes $0.053 \pm .041$ photons/cm^2-sec. The limit on the number of excess positrons annihilating locally is one-half of this number, which is a rather weak flux.

Indeed, one may also use the small counting excess in channels near 0.5 Mev to put an upper limit on the number of incident solar protons in the 1-15 Mev range stopping over Minneapolis. From the work of Hofmann and Winckler [1963], 0.5 Mev γ-rays are produced by p,n) and p,pn) interactions on N^{14} and O^{16}. These reactions result in new nuclei, which in addition to producing nuclear γ-rays from their excited states, are positron emitters in the ground state. Upon stopping, the positrons annihilate. Hofmann and Winckler quote about $4.5 \pm 1.5 \times 10^{-3}$ γ-rays per stopping proton in the 1.5 to 17 Mev range. Of these about 1/3 are due to positrons. Hence the number of γ-rays at 0.5 Mev per stopping solar proton will be about $1.5 \pm 0.5 \times 10^{-3}$.

If we assume <u>all</u> the excess counting rate in the channels near 0.5 Mev, 0.017 ± 0.014 counts/sec, is due to annihilation γ-rays from low energy proton interactions, we may obtain an extreme upper limit on their numbers. The maximum possible proton flux is 33 ± 27 protons/cm^2-sec. According to Pieper <u>et.al</u>., [1962], at only a few degrees of geomagnetic latitude further, and a different longitude, the flux at this time was $2 \times 10^3/\text{cm}^2$-sec. The magnetic cut-off therefore must have been extremely sharp. We will henceforth assume effects due to solar protons can be neglected.

Electron Spectrum and Positron Ratio

The differential photon spectrum $\varphi(E, \epsilon_o)$ produced by an electron of initial energy ϵ_o upon stopping is given by

$$\varphi(E, \epsilon_o) = \frac{N_o z}{A} \int_0^{R(\epsilon_o)} \frac{\sigma(E, \epsilon) d\epsilon}{d\epsilon/dX}$$

where $\sigma(E, \epsilon)$ is the cross section for an electron of energy ϵ to radiate a photon of energy E within a range dE in a layer dX thick, $\frac{d\epsilon}{dX}$ is the total rate of energy loss (radiation and collision) and $R(\epsilon_o)$ is the range of the electron. The function $\varphi(E, \epsilon_o)dE$ has been discussed by Anderson (1960) and by Kasper (1957) under suitable approximations. The curves of Kasper are reproduced in Figure 7. Note that φ vanishes as E approaches ϵ_o because an electron cannot radiate a photon with more than its initial energy.

In order to unfold simply the incident electron spectrum from the photon spectrum produced at the top of the atmosphere, the form of the electron spectrum has been assumed to be a power law;

$$N(\epsilon_o)d\epsilon_o = K\epsilon_o^{-\gamma}d\epsilon_o,$$

K and γ then become adjustable parameters. The differential photon spectrum produced by these electrons is then

$$N(E)dE = \int_E^{\infty} \varphi(\epsilon_o, E)N(\epsilon_o)d\epsilon_o dE.$$

The coefficient K is calculated such that the residuals of a least square fit to the data are minimized, using γ as a parameter. It was thought that the best fit for γ would be obtained when the residuals, plotted as a function of γ, were also at minimum. The results of carrying out this procedure as shown in Figure 8 gave a sharp minimum at $\gamma = 5.4$. However, as can be seen in Figure 6, the resultant photon spectrum does not fit the data too well at higher energy. Clearly, the power law does not represent the actual electron spectrum too well, and because of the steepness of the photon spectrum all the "fitting" is done to the data points at lowest energy. Intuitively, a better fit was obtained using $\gamma = 4.8$, as can be seen in Figure 5; at $\gamma = 4.0$, the number of low energy electrons is obviously too high. The power law differential electron spectrum with an exponent of 5.4, then fits the data very well below about 200 kev; at higher energies the spectrum must not be as steep.

Because of the divergence at low energies, the spectrum must eventually flatten out, and in order to compute the number of stopping electrons, an assumption must be made. The total number of electrons greater than 37 kev, N_T, obtained by integrating the power law, is also shown plotted in Figure 8 as a function of γ. This cut-off was chosen because no information is available on electrons of less energy. Fortunately, the most important physical quantity for the positron-electron ratio, N_T, varies only slowly with the power law exponent γ. Fitting with the extreme values of the data was done to give an estimate of the effect of statistical errors; although N and γ varied somewhat, N_T only changed about 10%. Cutting off the electron spectrum at 400 and 600 kev had little effect on N_T since there are so few high energy electrons. Using an exponential spectrum, as was done by Anderson, which also seems to be a better empirical relation for solar protons, was not tried for this electron precipitation.

The steep spectrum of precipitating electrons is in good agreement with that obtained previously by Anderson [1960] for events in the auroral zone. He obtained as exponents 5.0 to 5.5 for events in 1959 over College, Alaska and Fort Churchill. There is no *a priori* reason to expect electron precipitations under widely different conditions, locations, times and morphology to be identical; the fact that they are similar indicates the processes are related and probably differ only in detail.

The positron-electron ratio may now be obtained, by assuming as was done previously, that all the excess counts in channels 10-16 were due to positrons annihilating, and that these positrons were part of the general precipitation. The positron flux, averaged over the first influx is $0.026 \pm .020\ cm^{-2}sec^{-1}$. The number of electrons > 37 kev is found from the best-fit electron spectra to be $6.4 \times 10^7\ cm^{-2}\text{-}sec^{-1}$ averaged over the same time interval. Hence the ratio is $(4 \pm 3) \times 10^{-10}$, nearly five orders less than previously inferred. Most likely all the excess counts above 380 kev were due to photons produced by the high energy tail of the electron distribution. Furthermore, positrons of energy less than 37 kev, while not producing detectable x-rays, would still annihilate upon stopping.

Because of the steepness of the spectrum, there are probably many more undetected electrons stopping, than detected ones.

Hence the ratio obtained from the measurements, $(4 \pm 3) \times 10^{-10}$, must be regarded as an upper limit obtained under the most extreme assumptions, and is probably zero within experimental uncertainty. The actual positron-electron ratio may be several orders of magnitude less.

Discussion

The large flux of electrons, 6.4×10^{7} cm^{-2}-sec^{-1}, averaged over the 68 minute interval represents a loss from the trapped region of a total of 2.6×10^{10} electrons/cm^2 having energies above 37 kev. This is an order of magnitude larger than the daily average observed precipitating in the auroral zone by Anderson [1960], who finds weak x-ray fluxes present some 40% of the time, even during magnetically quiet intervals. These observations are undoubtedly related to those of O'Brien [1962] on Injun I. He often finds electrons in the loss cone at high latitudes. As noted by these observers, the large rate of precipitation is such that it would deplete the outer zone in a few hours. Therefore, in order to maintain the precipitation, an injection or acceleration mechanism is required which is rather efficient. The extreme extension of these ideas results in the so-called "splash-catcher" model of the outer zone, due to O'Brien [1962]. This model requires that nearly all the accelerated electrons precipitate immediately, the acceleration taking place in the loss cone. Only a few become trapped to form the outer zone as constructed from satellite observations.

Attempts to correlate directly the x-ray measurements on flight M-255 with direct electron measurements on Injun I did not prove successful because of the sporadic nature of the satellite observations [J. W. Freeman, private communication]. The conditions obtained during flight M-255 at Minneapolis may be comparable with those in the auroral zone during quieter times. This is because of the greater violence of the magnetic events, and the lowered cut-off for solar protons on 13 July.

Although it cannot be ruled out as a possibility, direct injection of energetic electrons in the earth's field from the solar plasma associated with the July 11 flare seems unlikely [Anderson, 1960]. Even less likely is the possibility that the electrons were accelerated in the flare of July 12, propagated with the solar protons, and entered the earth's field during the reduced magnetic cut-offs following the sudden commencement early on July 13. It also seems difficult to have thermal electrons in the plasma from the flare of July 11 enter the earth's magnetosphere, diffuse to line of force which connect with Minneapolis, and then become accelerated. If such were the case, of course the precipitating electrons would originally have been solar electrons, and the positron-electron ratio would be typical of solar electrons.

Most likely, however, the electrons observed during precipitations have their origin in the earth's field, and have been accelerated by some phenomena not yet well understood, but probably involving magnetic fluctuations. Since it is unlikely that either positrons or electrons would be preferentially accelerated, the ratio is then typical of plasma in the magnetosphere, as well as the energetic trapped electrons. Positrons, once they become embedded in the magnetosphere, would have a reasonable lifetime.

Annihilation of positrons has been discussed by Heitler [1957, p.268]. The cross-section is small for energetic positrons, and diverges as the velocity vanishes. Accordingly, it is more appropriate to discuss the lifetime of slow positrons, Heitler finds the reciprocal of the <u>lifetime</u>, τ, to be

$$1/\tau = NZ\pi r_e^2 c \text{ sec}^{-1},$$

where r_e is classical electron radius, and the positrons are annihilating in matter whose density is N atoms/cm^{-3} of charge Z. The lifetime is condensed matter such as lead is about 10^{-10} seconds, at balloon altitudes it is about 10^{-5} seconds, at ~~400~~ 1000 km (lower magnetosphere) it is about a week. In the interplanetary medium, where the density may be about 500 cm^{-3} the lifetime becomes 10^4 years.

If then, by some mechanism, positrons at low energy were being injected into the magnetosphere, they could remain essentially stored until they became accelerated and appeared as energetic precipitating particles. The low positron-electron ratio of these particles puts a limit on the rate of injection, dependent of course on the model used.

Although it seems unlikely, as previously discussed, the possibility exists that the observed particles had their origin in the solar atmosphere; that is, the plasma ejected in the flare of July 11 entered the earth's field and eventually appeared as an electron precipitation. This solar plasma could have trapped in it positrons, either thermal or energetic, produced either in nuclear reactions or other processes at the time of the flare. The lifetime would be much longer than the few days required for the interplanetary propagation. Under these assumptions, the measured limit of the positron-electron ratio applies also to the solar chromosphere.

It is also possible that a real flux of positrons could be injected directly into the earth's field via cosmic-ray produced secondaries. An anti-neutron, for example, would introduce positrons upon decaying. Such particles of course would be produced only in nuclear encounters of extreme energy, and would tend to be directed strongly downward into the atmosphere. Furthermore they would annihilate before thermalizing, so the injection rate would be low. Positive albedo pions and muons also decay to positrons; however, their lifetime is so short that few would decay in the trapping region. Neutral mesons also produce positrons copiously, [Peterson, 1962] some of which, if ejected upward, could suffer a coulomb deflection and become trapped. All these sources would produce energetic positrons, which would have to become untrapped during the electron precipitation and enter the atmosphere along with the auroral-like electrons. Since the number of such positrons was observed to be very small, it seems that a limit on the cosmic-ray injection processes could be derived.

It is possible to compare the limit of the positron-electron ratio implied for the magnetosphere, and possibly the solar chromosphere with that of other extraterrestrial matter. The limit of the flux at 0.5 Mev incident at zero depth is a measure of the slow positron density of all matter to distances at which the red-shift is significant. The lowest flux limit in space at 0.5 Mev has been obtained by Arnold, et.al., [1962] with a detector on the Ranger III moon probe. He obtains a limit of 0.01 photons/cm^2-sec.

The flux of γ-rays at 0.5 Mev passing through a sphere of radius r produced by a uniform density N cm^{-3} in which there is a positron-electron ratio is γ

$$F = 2/3 \; r \; \gamma \; N^2 \; \pi^2 \; r_e^2 c.$$

We assume neglectable absorption of γ-rays. If in the interplanetary medium $N = 500$ cm^{-3}, we may compute the flux generated due to positrons annihilating in matter inside a sphere of 1 A.U. radius. Alternately, we may use these assumptions, and the upper limit of the $\frac{1}{2}$ Mev flux, to put an independent upper limit on the positron electron ratio of the interplanetary medium. This upper limit of γ is 5×10^{-6}, not nearly as low as the one obtained by the direct measurement for the precipitating electrons.

Almost certainly the ratio in the interplanetary medium must be closer to that in the magnetosphere, and the limit implied by the extra-terrestrial γ-ray flux regarded as an insensitive measurement of the ratio for planetary regions. It is difficult to believe that the two media have such a radically different origin that their positron-electron ratio differs by 10^4. Since these plasmas are in contact at the outer boundary of the earth's field, a continuous exchange of particles must take place, at least after many solar and magnetic disturbances. Hence the two media would become essentially undistinguished, in terms of microscopic structure. On the other hand, if indeed the solar plasma of recent origin had a markedly different ratio, then by measuring this ratio at various points in the solar-terrestrial complex, one could trace the history of a piece of solar matter as it propagates to the earth, into the magnetic field, and finally is catastrophically removed of its positrons by precipitation into the earth's atmosphere.

We may also use the same idea to put an upper limit on the ratio in the galaxy. Assuming the earth is near the edge of a galaxy of radius r_g, and thickness t, which has negligible absorption at 0.5 Mev, the flux would be

$$F = \frac{1}{2}\, t\, \gamma\, N^2\, \pi^2\, r_e^2 c.$$

If we take $t = 10^{21}$ cm, $N = 1$ atom cm^{-3}, $F \leq .01$ photon cm^2-sec, the upper limit ratio is 2.5×10^{-9}. Thus the upper limit of the ratio of slow positrons to electrons in the galaxy as a whole is somewhat greater than that presently available for these precipitating from the magnetosphere. Of course the ratio could be much larger in accelerated electrons, such as those which give the synchroton radiation from the galaxy, since these annihilate at a very low rate. If indeed there is symmetry between the number of particles and anti-particles in the universe, it is apparent the anti-matter must be well isolated from ordinary matter, and that it is not located in the near regions of space with any presently detected density.

Summary

From balloon measurements of the x-ray spectrum to 600 kev during an electron precipitation at Minneapolis associated with the solar events of the July 1961 series, the intensity near 0.5 Mev, and the electron spectrum have been determined. These allow a determination of the positron-electron ratio of the energetic electrons to be $4 \pm 3 \times 10^{-10}$. This may be interpreted as an upper limit for the ratio of all positrons to electrons in the magnetosphere plasma, and possibly for that in the interplanetary median and the solar chromosphere. This remarkably low ratio puts extreme restraints on energetic processes involved in the generation and acceleration of those electrons. The ratio may be compared with the ratio for the interplanetary matter of 5×10^{-6} and the interstellar matter of 2.5×10^{-9}, obtained from the limit of the extraterrestrial flux at 0.5 Mev.

Acknowledgements

This work was supported under NASA contracts NASw-56 at Minnesota and NsG-318 at La Jolla. The balloon flight, logistics support, and the data from other flights were obtained from the High Altitude Monitoring project, supported by the Atmospheric Science Division of the National Science Foundation. The interest of Dr. J. R. Winckler in this work is gratefully acknowledged. The apparatus was designed and constructed by John Nitardy and Jerry Anderson, and the data reduction was performed by Jim Peterson of the University of Minnesota. Thomas Delmer of the University of California, San Diego computed the electron spectrum.

Appendix

In this appendix we indicate the corrections to the measured counting rate spectrum to obtain the differential flux at zero depth. The rate of a detector at depth h due to an isotropic source of differential spectrum N(E) in a channel of width ΔE from a solid angle $\sin\theta d\theta d\varphi$ is

$$R(E,h) = \frac{N(E)\eta(E)}{4\pi} \int_0^{2\pi} \int_0^{\pi/2} G(\theta,\varphi)\, e^{-\mu h/\cos\theta} \sin\theta d\theta d\varphi\, \Delta E$$

The usual polar coordinates are θ and φ, and μ is the total attenuation coefficient (Compton plus photo). The efficiency $\eta(E)$ which is given in Table II has been obtained from the work of Reynolds, Miller and Snow [1957]. Since the projected area of the counter is circularly symmetric about φ, and changes only slowly with θ, we can use the geometry factor $G_o = \pi/4\, LD(1 + D/2L)$ for an isotropic flux, and remove $G(\theta,\varphi)$ from the integration. For the NaI crystal used $G_o = 6.34\ cm^2$. We will assume photons initially at a higher energy E' scattering into the channel at energy E produce a negligible fraction of the rate. This is valid because of the steepness of the spectrum and the small depth of the balloon (less than one mfp. at most energies being considered).

If the entire attenuation were due to the atmosphere, the expression

$$\int_0^{\pi/2} e^{-\mu h/\cos\theta} \sin\theta d\theta$$

would be the Gold integral $E_1(\mu h)$. However, the copper G-M counter of this apparatus was positioned vertically over the scintillator, and produced significant absorption at low energies. We use the approximation that the 1"O.D × 2.5" long tube with an .032" wall can be represented as a disk of the same area, and three thicknesses of wall located at the center of the actual counter. This shields the scintillator from above with 2.4 gm/cm^2 of copper over a solid angle $\Delta\Omega$ = 0.82 steradian. The number of photons counted in the detector, including losses in the GM counter, is then

$$R(E,h) = \frac{G_o\eta(E)}{4\pi} \int_0^{2\pi} \left[\int_0^{\theta_1} e^{-\mu h/\cos\theta} e^{-\mu\bar{t}/\cos\theta} + \int_{\theta_1}^{\pi/2} e^{-\mu h/\cos\theta} \right] \sin\theta d\theta d\varphi N(E)\Delta E$$

This may be simplified since the angle θ over which the shielding is effective is small. Then

$$R(E) = \frac{G_o\eta(E)}{2} \left[E_1(\mu h) - \frac{\Delta\Omega}{2\pi} e^{-\mu h} (1 - e^{-\mu\bar{t}})\right] N(E)\Delta E$$

where $\bar{t}$ = 1.07 t is an average thickness over the solid angle $\Delta\Omega$. The bracketed factor, called $C(h,E)$, depends only on the atmospheric depth and the energy through the attentuation coefficients of air and copper. $C(h,E)$ is given in Table II for the median energies of each channel.

References

Anderson, K.A., and D.C. Enemark, Balloon Observations of X-Rays in the Auroral Zone II, J.Geophys.Res., 65 (11) 3521-3538, 1960.

Arnold, J.R., et. al., Gamma Rays in Space, Ranger 3, J.Geophys.Res., 67 (12) 4878-4880, 1962.

Arnoldy, R.L., R.A. Hoffman, and J. R. Winckler, Observation of the Van Allen Radiation Regions during August and September 1959, 4, The Outer-Zone Electrons, J.Geophys.Res, 67 (7), 2595-2612, 1962.

Heitler, W., The Quantum Theory of Radiation, third edition, Oxford, 1957.

Hofmann, D.J. and J.R. Winckler, Simultaneous Balloon Observations at Fort Churchill and Minneapolis during the Solar Cosmic-Ray Events of July 1961, J. Geophys. Res., 68 (8), 2067-2098, 1963.

Kasper, J.E., State University of Iowa, unpublished manuscript, 1957.

Masley, A.J., T.C. May and J. R. Winckler, Analysis of Balloon Observations during the April 1960 Solar Cosmic-Ray Event, J. Geophys.Res., 67 (9), 3243-3268, 1962.

Miller, W.F., J. Reynolds, and W. J. Snow, Efficiencies and Photo-fractions for Sodium-Iodide Crystals, Rev. Sci. Instr., 28 (9), 717-719, 1957.

O'Brien, B.J., Direct Observations of Dumping of Electrons at 1000-Kilometer Altitude and High Latitudes, J.Geophys.Res., 67 (4), 1227-1234, 1962.

Peterson, L.E., The 0.5-Mev Gamma-Ray and the Low-Energy Gamma-Ray Spectrum to 6 Grams per Square Centimeter over Minneapolis, J.Geophys.Res., 68 (4), 979-987, 1963.

Peterson, L.E., and J. H. Nitardy, Simple Circuit for a Phoswich Scintillation Counter, Rev. Sci. Instr., 32 (12), 1390-1392, 1961.

Pieper, G.R., et. al., Solar Protons and Magnetic Storms in July 1961, J.Geophys.Res., 67 (13), 4959-4981, 1962.

Winckler, J.R., et. al., A Study of the Precipitation of Energetic Electrons from the Geomagnetic Field during Magnetic Storms, J. Geophys.Res., 67 (10), 3717-3736, 1962.

Table 1

Analysis Intervals for Flight M-255 13 July 1961

Event	Start	U.T.	End
First burst	2057:45		2205:45
Transition period	2209:45		0040:30 14 July
Second burst	0040:30		0143:39
Transition period	0147:34		0336:00
Quiet time	0339:45		0541:30

Table II

Parameters used in obtaining the differential energy spectrum at production from the excess counting rates measured on the balloon.

$$G_o = 6.34\ cm^2 \qquad \Delta E = 37\ kev$$

Channel number	Mean energy kev	Efficiency	C(h,E)	F(E)	Excess rate counts/sec	Differential spectrum
1	55	1.0	0.084	9.8	92.8±0.7	9.45±.07 n/cm^2-sec-kev
2	85	1.0	0.123	14.4	19.2±0.5	1.33±.03
3	125	1.0	0.157	18.3	4.26±0.23	0.29±.01
4	170	0.88	0.188	19.3	1.62±0.2	.074±.006
5	210	0.75	0.208	18.3	0.51±.08	.028±.006
6	255	0.64	0.228	16.4	0.33±0.10	.020±.006
7	300	0.55	0.247	16.4	0.09±.065	.0055±.003
8	340	0.49	0.260	14.7	0.04±.06	.0027±.004
9	380	0.44	0.273	14.0	0.13±.07	.0093±.0057
Average 10-16		0.33	0.308	12.0	.017±.013	.0014±.0012
Line at 0.5 mev				0.322	.017±.013	.053±.041 n/cm^2-sec

Figure Captions

Figure 1 A sketch indicating the method of detecting positrons in precipitating electrons. Stopping electrons and positrons produce x-rays via Bremsstralhlung; a positron produces additionally annihilation γ-rays. The number and spectrum of electrons and positrons can be obtained from the γ-ray spectrum observed at balloon altitudes.

Figure 2 Time history of various events during the balloon flight on July 13, 1961. The first x-ray influx was in progress and in a decay phase when the balloon reached altitude. Although generally disturbed, no outstanding magnetic feature marks the x-ray event.

Figure 3 Sequence of observations during the July 1961 series obtained by the Minnesota group at Fort Churchill and Minneapolis. Injun I measured solar protons at magnetic latitudes nearly as far south as Minneapolis during flight M-255. Large auroral x-ray events were also in progress at Fort Churchill.

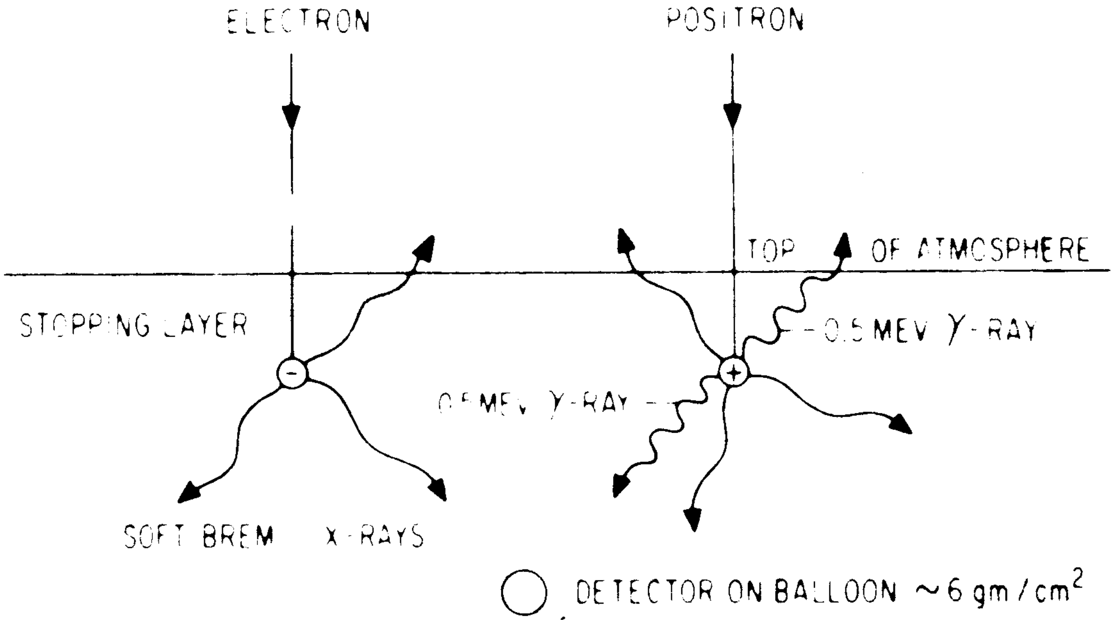
Figure 4 Counting rate spectra obtained from the scintillation counter during the flight. The period taken as a quiet time reference, just before termination, is compared with previous results. This spectrum is due to cosmic-ray produced background. The much steeper spectrum due to the x-ray event is shown averaged over the first 68 minutes at 6 gm/cm^2 depth. X-ray influxes later in the flight had a similar spectrum.

Figure 5 Excess counting rates during the first influx. This is obtained by subtracting the spectra of Figure 3. The statistical significance at the higher energies has been improved by averaging channels 10 to 16 together, and then subtracting. Obviously there were very few γ-rays produced near 0.5 Mev during the event.

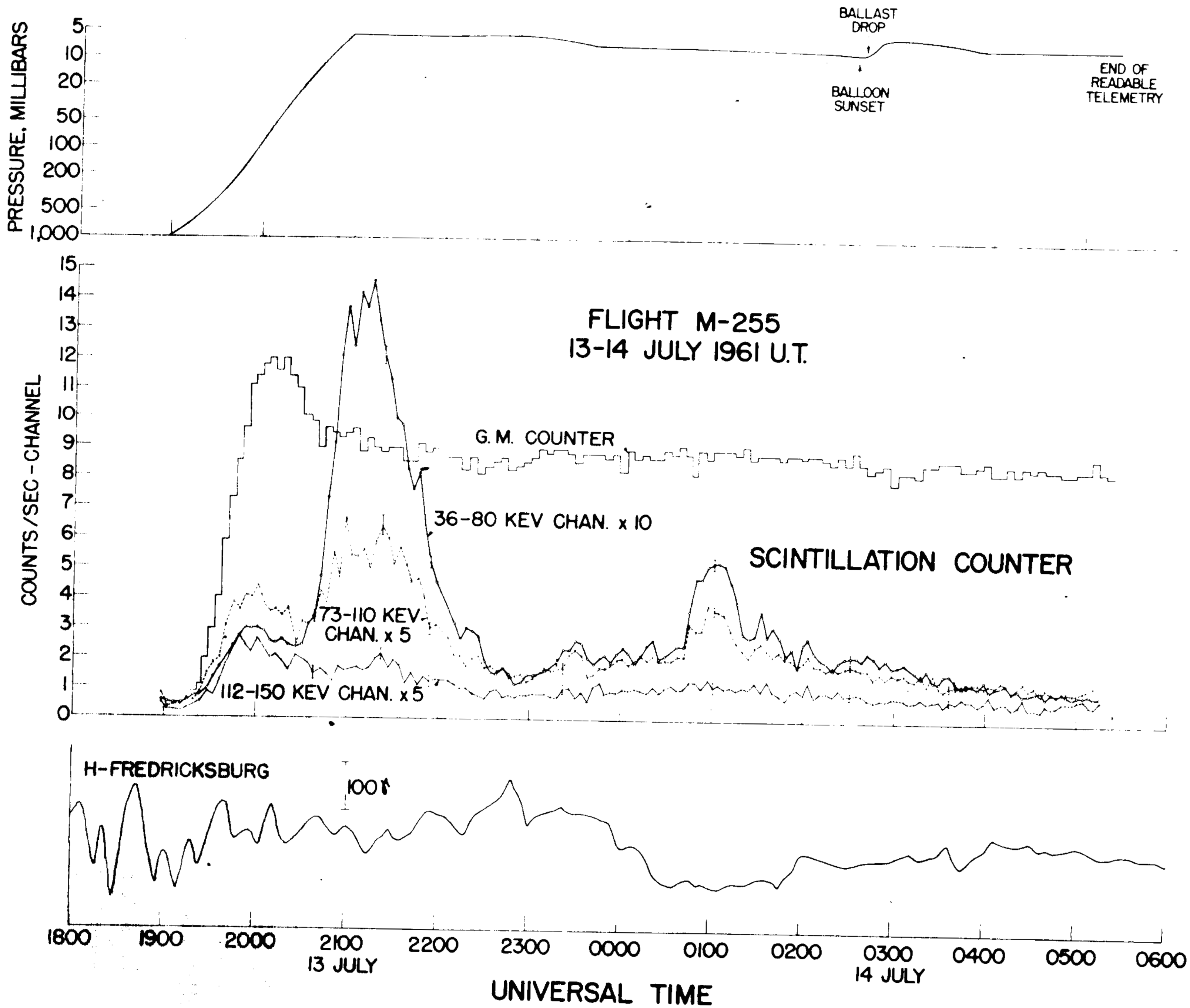
Figure 6 The x-ray differential spectrum corrected to zero depth. Errors in the correction process have not been included. Also shown is the photon spectrum which would be produced by an electron spectrum of the form $K\,E^{-\gamma}$, where K has been chosen to minimize the residuals. The index $\gamma = 5.4$, while giving the best fit at low energies, is obviously too steep at high energies.

Figure 7 The x-ray spectrum produced by an electron of energy ϵ_o upon stopping in air. These curves, taken from an unpublished work of J. E. Kasper, are used to unfold the electron spectrum from the photon spectrum.

Figure 8 The results of least square fitting the photon spectrum produced by a power law electron spectrum. Although the residuals, σ^2, went through a sharp minimum, the total number of electrons greater than 37 Kev varied only slowly with the exponent γ.

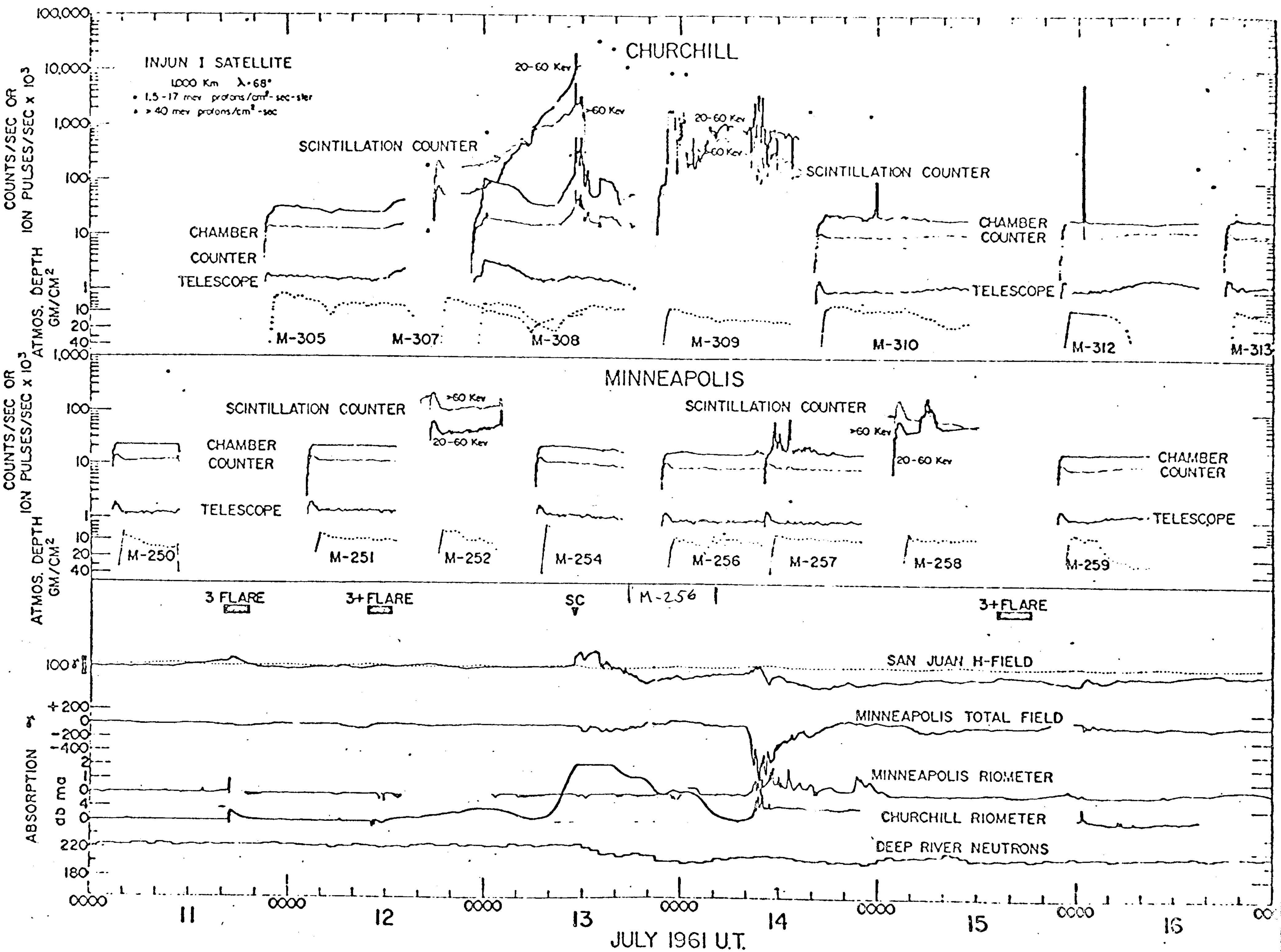


POSITRON EXPERIMENT



PRESSURE, MILLIBARS
5
10
20
50
100
200
500
1,000
BALLAST DROP
BALLOON SUNSET
END OF READABLE TELEMETRY
COUNTS/SEC-CHANNEL
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
FLIGHT M-255
13-14 JULY 1961 U.T.
G. M. COUNTER
36-80 KEV CHAN. x 10
SCINTILLATION COUNTER
73-110 KEV CHAN. x 5
112-150 KEV CHAN. x 5
H-FREDRICKSBURG
100γ
1800
1900
2000
2100
13 JULY
2200
2300
0000
0100
0200
0300
14 JULY
0400
0500
0600
UNIVERSAL TIME

Figure 2



CHURCHILL
INJUN I SATELLITE
1,000 Km λ=68°
• 1.5-17 mev protons/cm²-sec-ster
• > 40 mev protons/cm²-sec
SCINTILLATION COUNTER
CHAMBER
COUNTER
TELESCOPE
20-60 Kev
>60 Kev
M-305
M-307
M-308
M-309
M-310
M-312
M-313
MINNEAPOLIS
M-250
M-251
M-252
M-254
M-256
M-257
M-258
M-259
3 FLARE
3+FLARE
SC
SAN JUAN H-FIELD
MINNEAPOLIS TOTAL FIELD
MINNEAPOLIS RIOMETER
CHURCHILL RIOMETER
DEEP RIVER NEUTRONS
COUNTS/SEC OR ION PULSES/SEC x 10³
ATMOS. DEPTH GM/CM²
ABSORPTION db ma
JULY 1961 U.T.

FIG. 3

COUNTING RATE SPECTRA

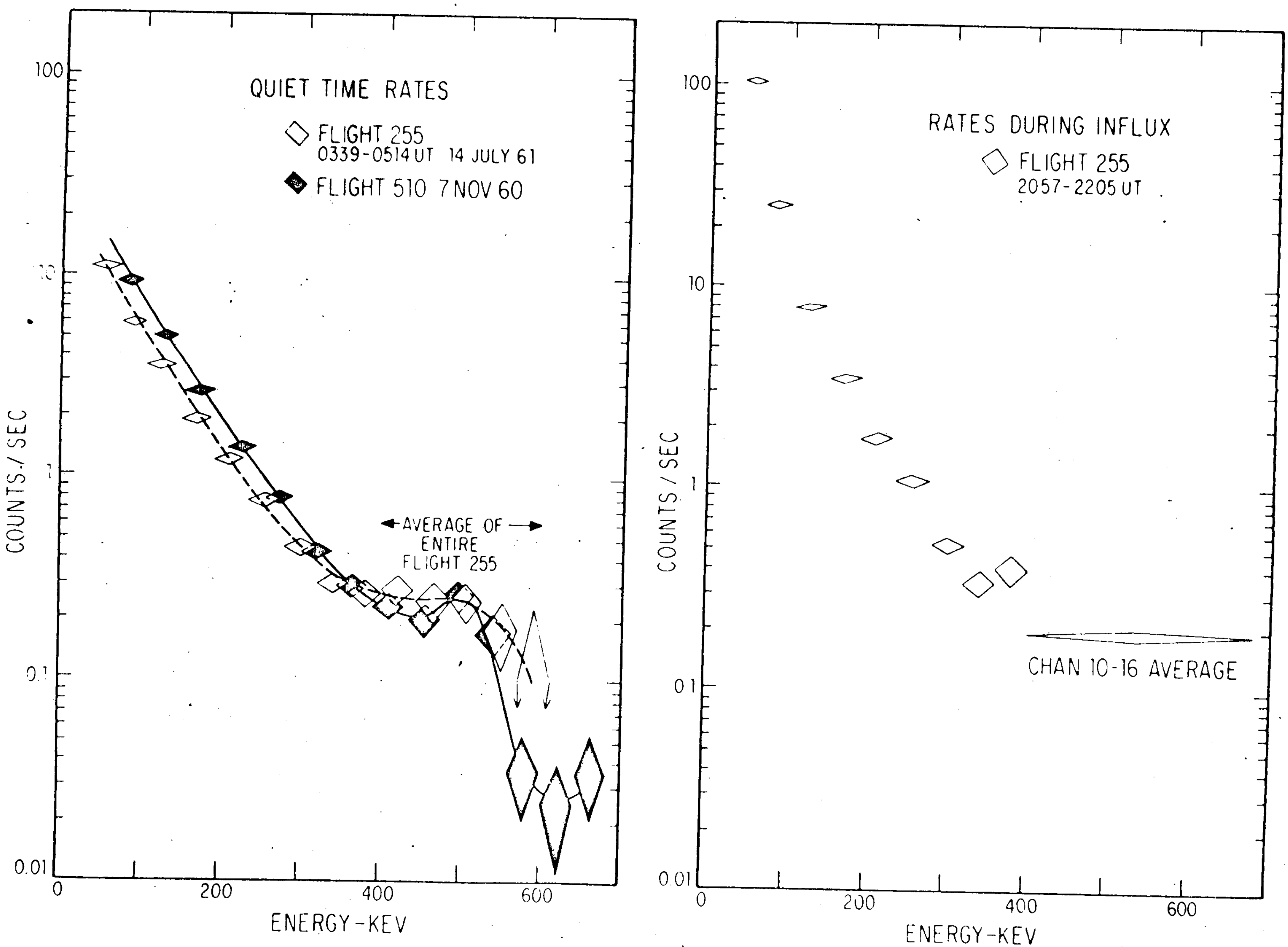


Figure 4

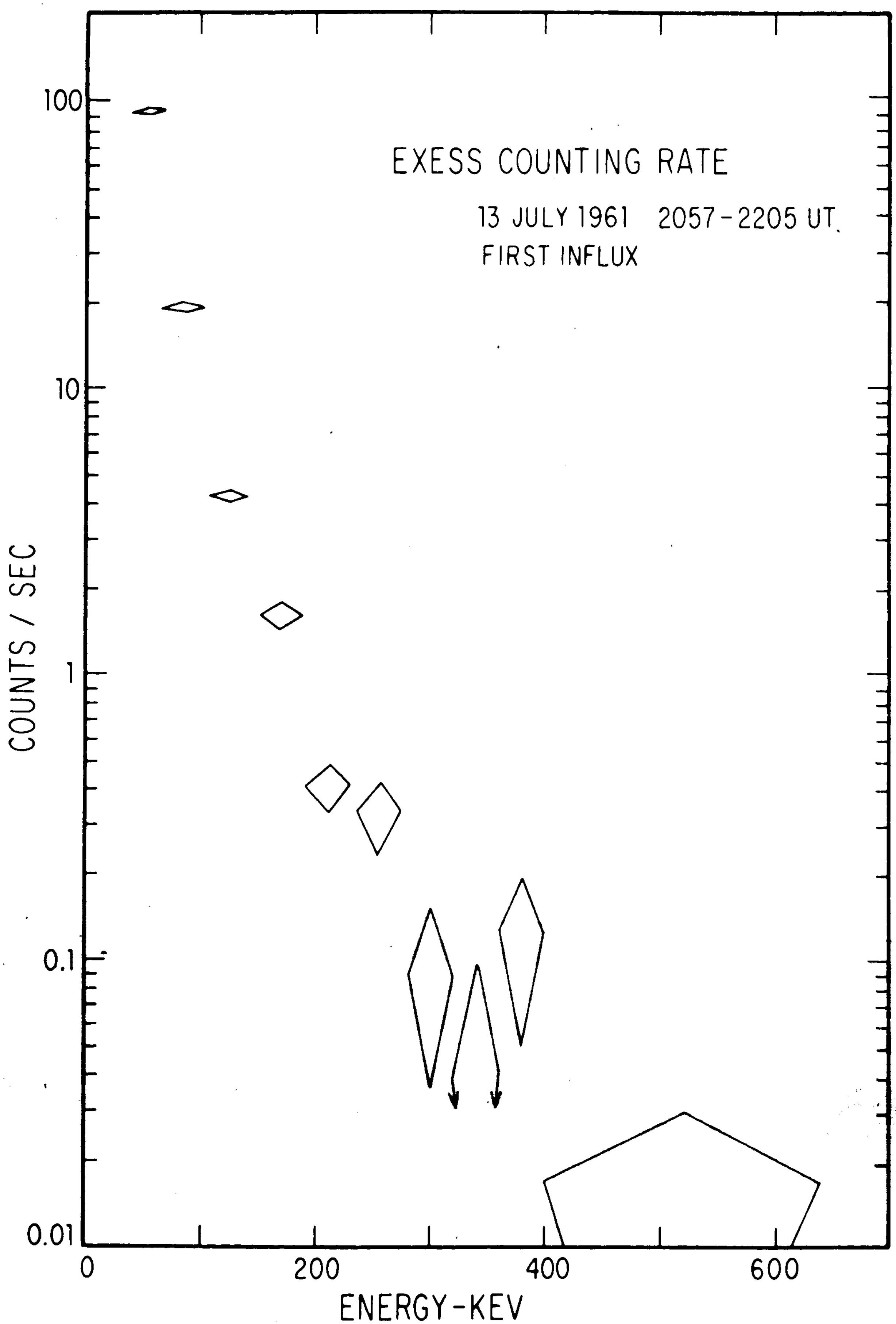
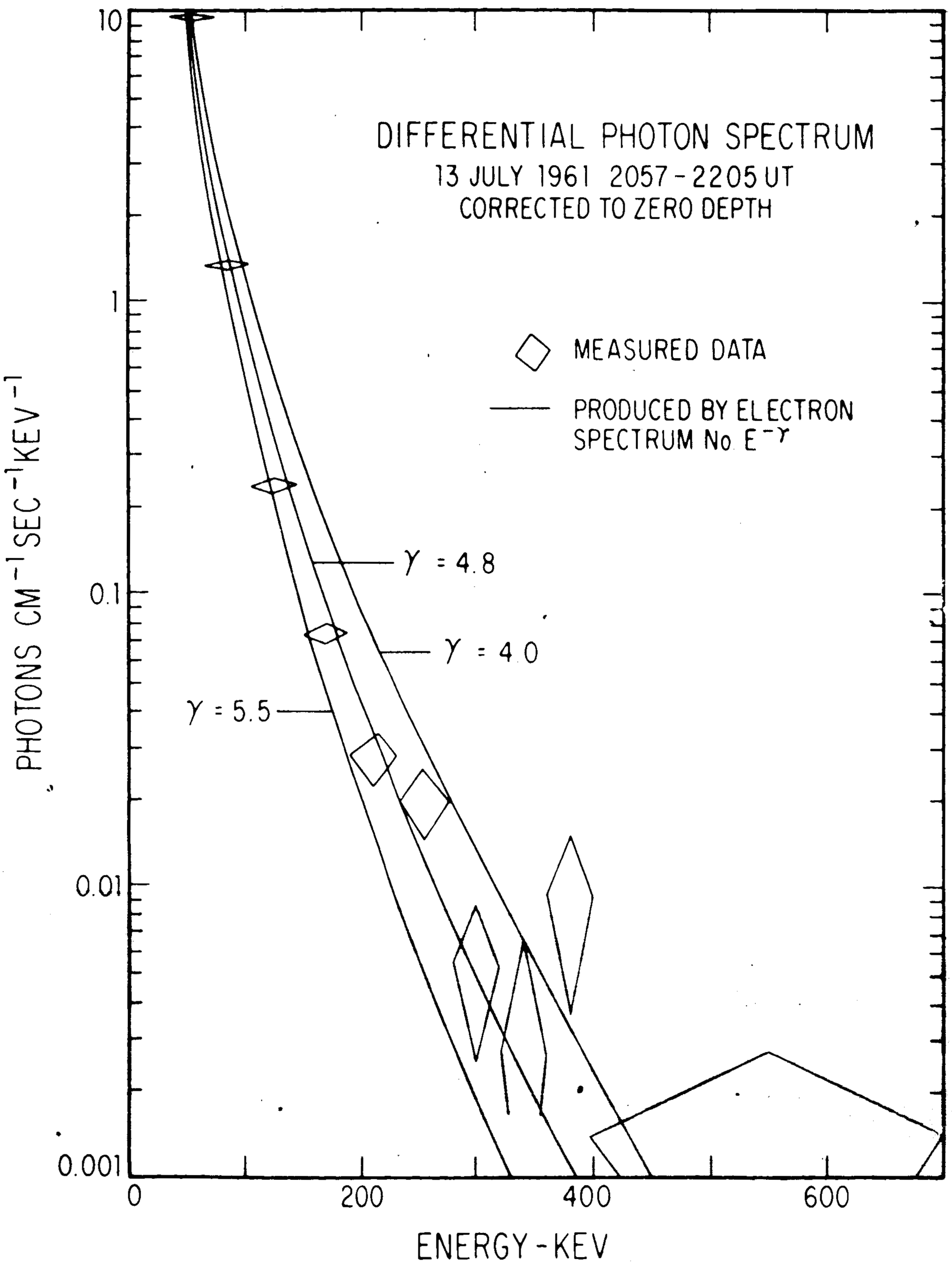
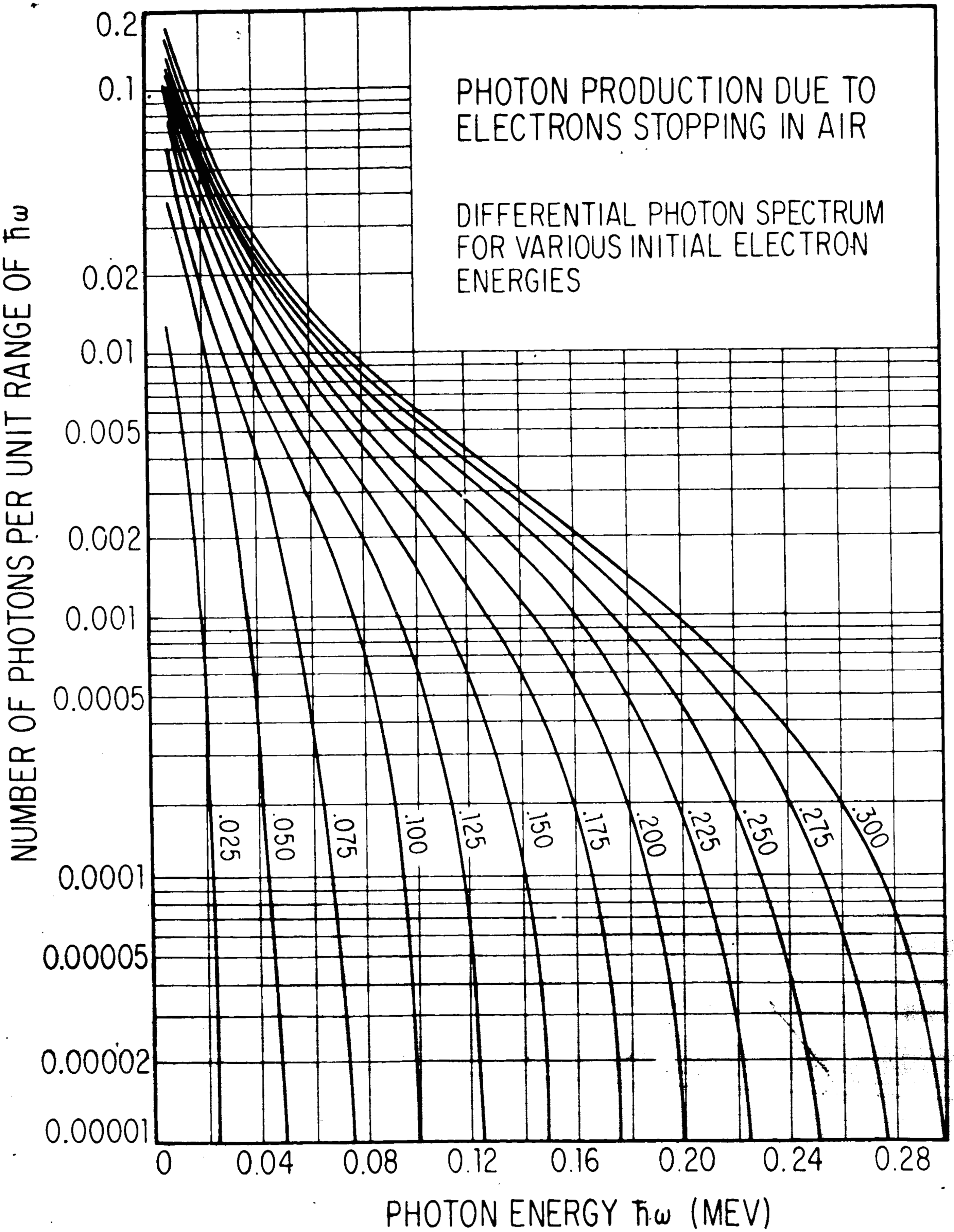

EXESS COUNTING RATE
13 JULY 1961 2057-2205 UT.
FIRST INFLUX
COUNTS / SEC
100
10
1
0.1
0.01
0
200
400
600
ENERGY-KEV

Figure 5



DIFFERENTIAL PHOTON SPECTRUM
13 JULY 1961 2057-2205 UT
CORRECTED TO ZERO DEPTH
MEASURED DATA
PRODUCED BY ELECTRON SPECTRUM No E^-γ
γ = 4.8
γ = 4.0
γ = 5.5
PHOTONS CM^-1 SEC^-1 KEV^-1
10
1
0.1
0.01
0.001
0
200
400
600
ENERGY-KEV

Figure 6



PHOTON PRODUCTION DUE TO ELECTRONS STOPPING IN AIR
DIFFERENTIAL PHOTON SPECTRUM FOR VARIOUS INITIAL ELECTRON ENERGIES
NUMBER OF PHOTONS PER UNIT RANGE OF ħω
0.2
0.1
0.02
0.01
0.005
0.002
0.001
0.0005
0.0001
0.00005
0.00002
0.00001
.025
.050
.075
.100
.125
.150
.175
.200
.225
.250
.275
.300
0
0.04
0.08
0.12
0.16
0.20
0.24
0.28
PHOTON ENERGY ħω (MEV)

Figure 7

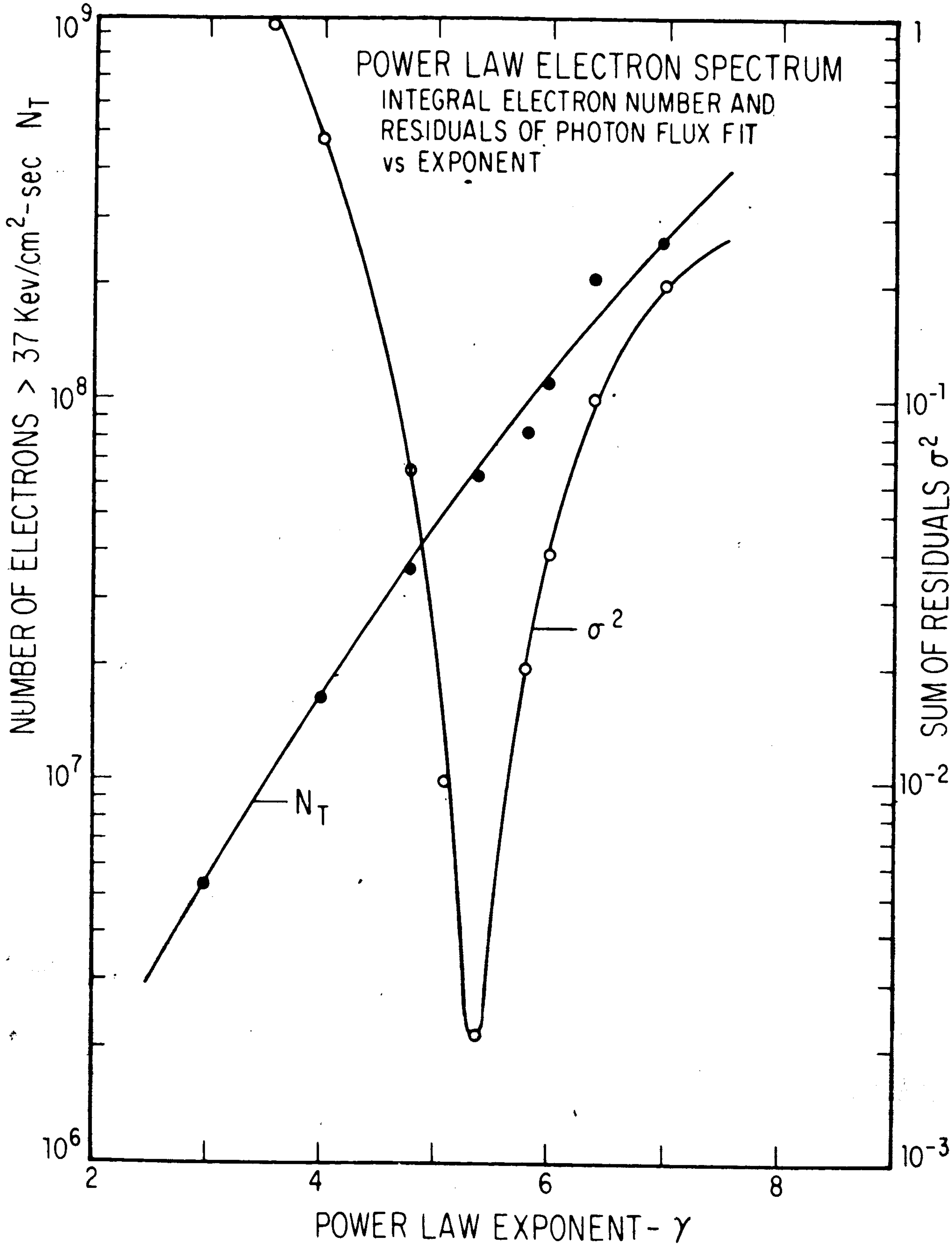

POWER LAW ELECTRON SPECTRUM
INTEGRAL ELECTRON NUMBER AND RESIDUALS OF PHOTON FLUX FIT vs EXPONENT
NUMBER OF ELECTRONS > 37 Kev/cm^2-sec N_T
SUM OF RESIDUALS σ^2
POWER LAW EXPONENT - γ
N_T
σ^2
10^9
10^8
10^7
10^6
1
10^{-1}
10^{-2}
10^{-3}
2
4
6
8

Figure 8